Transportation Consortium of South-Central States

Tran-SET

Solving Emerging Transportation Resiliency, Sustainability, and Economic Challenges through the Use of Innovative Materials and Construction Methods: From Research to Implementation

Enhancing Evaluation of Wildlife Detection Systems

Project No. 19SAUNM03

Lead University: University of New Mexico

Final Report

August 2020

Disclaimer

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Every year in the United States, wildlife-vehicle collisions (WVCs) cause 200 human fatalities, 26,000 human injuries, and substantial harm to wildlife populations, resulting in approximately $8.4 billion in total costs. The research team examined two US 64 bridges located near Lumberton, New Mexico that were designed to allow wildlife to cross underneath. Monitoring stations were positioned at each of the crossings so that both wildlife approaches and passages were observed. Special mounting brackets were designed and fabricated to allow for the installation of monitoring equipment. Wildlife observations were supplemented with WVC counts. Over seven months of study, nearly 100,000 wildlife photos were captured consisting of 1,438 individual animals using the crossing structures. Both crossings saw passage rates of approximately 80%. Findings suggest that elk and deer used both the smaller and larger crossings. Elk predominated during December through March while deer predominated during May through June, with most crossings occurring during defined nighttime peaks. There have been no elk and fewer deer collisions since the wildlife crossing system was installed. WVCs that have occurred were near the ends of the wildlife fencing, suggesting that fencing extent may be a factor that warrants further research. Lessons learned through this project help develop our understanding of WVCs, contributing to our goal of saving lives – both human and wildlife – and enhancing wildlife conservation efforts.</td></tr>
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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

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ACRONYMS, ABBREVIATIONS, AND SYMBOLS

AADT	Annual Average Daily Traffic
AZGFD	Arizona Game and Fish Department
CBC	Concrete Box Culvert
FHWA	Federal Highway Administration
GIS	Geographic Information System
MP	Mile Post
NM	New Mexico
NMDGF	New Mexico Department of Game and Fish
NMDOT	New Mexico Department of Transportation
US	United States of America
WVC	Wildlife-Vehicle Collision

EXECUTIVE SUMMARY

Every year in the United States (US), wildlife-vehicle collisions (WVCs) cause 200 human fatalities, 26,000 human injuries, considerable property damage, and substantial harm to wildlife populations, resulting in approximately $8.4 billion in total costs.

To avoid WVCs, roadway engineers have two choices: 1) warn motorists of the presence of wildlife on the roadway or 2) provide wildlife with a way to avoid entering the travel way. To achieve the former, methods of detecting wildlife and warning motorists must be utilized. We focus on the more-popular latter approach, for which a variety of wildlife crossing structures are employed. These structures include various underpasses and overpasses. To ensure that wildlife utilize a crossing structure, crossing systems typically include game fencing to channel wildlife to the crossing structure.

While WVC mitigation is becoming popular, questions still remain. Which crossing structures are most effective and for which species of wildlife? How much game fencing is needed to effectively direct wildlife to a crossing structure? What is the best way of monitoring wildlife to explore the above questions? A lack of research exists regarding these research questions and therefore requires further investigation.

To answer the above research questions, the research team examined two wildlife crossing structures along US 64 located near the town of Lumberton, New Mexico (NM) in the mountainous northern part of the state. Both crossings are US 64 highway bridges over Amargo Creek, with the wildlife crossing under the highway and along the creek. One bridge is relatively small at 110 feet in length while the other is larger at 310 feet in length. A three-mile stretch of highway had wildlife fencing installed in 2012 that was designed to funnel wildlife to the two monitored crossings. Past road ecology research by the New Mexico Department of Transportation (NMDOT), Arizona Game and Fish Department (AZGFD), and New Mexico Department of Game and Fish (NMDGF) inform the design of our monitoring sites.

Novel wildlife detection technologies – including Reconyx PC800 HyperFire professional semi-covert infrared cameras with custom mounting brackets – allowed us to understand how much and what type of wildlife utilized the crossing structures. Monitoring sites were positioned at each of the crossings so that both wildlife approaches and passages were observed, allowing for passage rates to be calculated. Special mounting brackets were designed and fabricated to allow for the installation of monitoring equipment while avoiding of vandalism and theft. Wildlife observations were supplemented with WVC counts queried from NMDOT motor vehicle collision data to further explore the effectiveness of the crossing structures.

At the time of this report, seven months of wildlife crossing data was collected. While the developed methodology is the focus of this report, we provide a preliminary analysis of the seven months of data that we have collected up to this point. The implementation report will have twelve months of data, allowing for a more complete understanding of wildlife patterns across all seasons.

Over the seven months of study (mid-November 2019 to mid-June 2020), nearly 100,000 wildlife photos were captured consisting of 1,438 individual animals. Wildlife approaches and crossings were more frequent at the larger bridge. However, both crossings saw passage rates of approximately 80%, meaning that 80% of animals that approached the crossings ended up using the crossings. Or in other words, animals were not afraid to use the crossings, showing that the structures are effective in size and design. Detections primarily consisted of elk and deer, along with fewer sightings of bobcat, coyote, foxes, and other species. Findings suggest that elk and deer used both the smaller and larger crossings, which is important as it was unclear whether the small structure would provide enough clearance. Elk predominated during December through March while deer predominated during May through June. Elk used the crossings most frequently between approximately 22:00-02:00 and 06:00-08:00. Deer peaks were similar but a little earlier with peaks around 19:00-21:00 and 05:00-07:00. Wildlife crossings were predominately southbound in early winter and northbound in late winter and spring.

WVCs have decreased significantly since the wildlife crossing system installation in 2012. There have been no elk collisions in the six years proceeding installation (six elk collisions were reported in the eight preceding years). Deer collisions have also decreased from five collisions in the eight preceding years to one collision in the six proceeding years. WVCs that occurred post-installation were near the ends of the wildlife fencing, suggesting that the fencing extent may be a factor that warrants further research.

This project plays an important role in three larger projects: 1) an on-going collaboration between NMDOT and AZGFD exploring WVC mitigation effectiveness, which is currently entering Phase 2; 2) a multi-state pooled fund study organized by several western states exploring WVC mitigation effectiveness; and 3) the New Mexico Wildlife Corridors Act, SB228, focused on WVC mitigation, which was recently passed through the New Mexico legislature. Lessons learned through this project will help advance the efforts mentioned above and develop our understanding of WVCs, contributing to our goal of saving lives (both human and wildlife) and enhancing wildlife conservation efforts.

1. INTRODUCTION

The over four million miles of public roads in the US comprise the largest road network in the world *(1)*. This vast network connects diverse communities across the country and enables our economy to prosper. However, the road network also disrupts native wildlife populations both in terms of their habitats and their movements (Figure 1). In addition to natural wildlife movement disruption, vegetation promoted by landscape disturbance can attract additional wildlife to roadside environments, further increasing the likelihood of wildlife-human interaction.

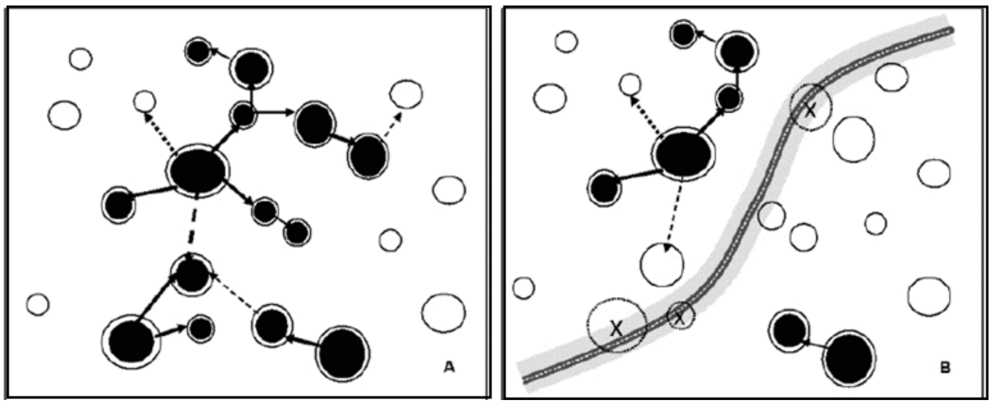

Figure 1. Wildlife populations are linked to each other through movements along migratory corridors (left). When a roadway is installed, populations' natural habitats and movements are disrupted (right). When populations are divided, the entire population risks extinction *(2)*.

Every year in the US, WVCs cause 200 human fatalities, 26,000 human injuries, considerable property damage, and substantial harm to wildlife populations, resulting in approximately $8.4 billion in total costs *(3, 4)*. The problem is vast, with over 1.5 million WVCs involving deer alone each year in the US *(5)*.

For many highways in rural New Mexico and other rural parts of the US, WVCs are the most prevalent type of motor vehicle collision. For example, NM 537 in northern New Mexico between Cuba and Dulce had 44 reported motor vehicle collisions from 2015 to 2017. 37 of these collisions involved wildlife, representing 84% of the total collisions. For over 120 highway sections in New Mexico, at least half of the motor vehicle collisions reported are WVCs (Figure 2). These highways can be found in every corner of the state. A three-mile section of US 180 east of Silver City experienced 71 reported WVCs from 2015 to 2017, meaning there were nearly eight WVCs per mile per year, the highest rate in the state. WVCs are one of the most pressing safety issues for highways in New Mexico.

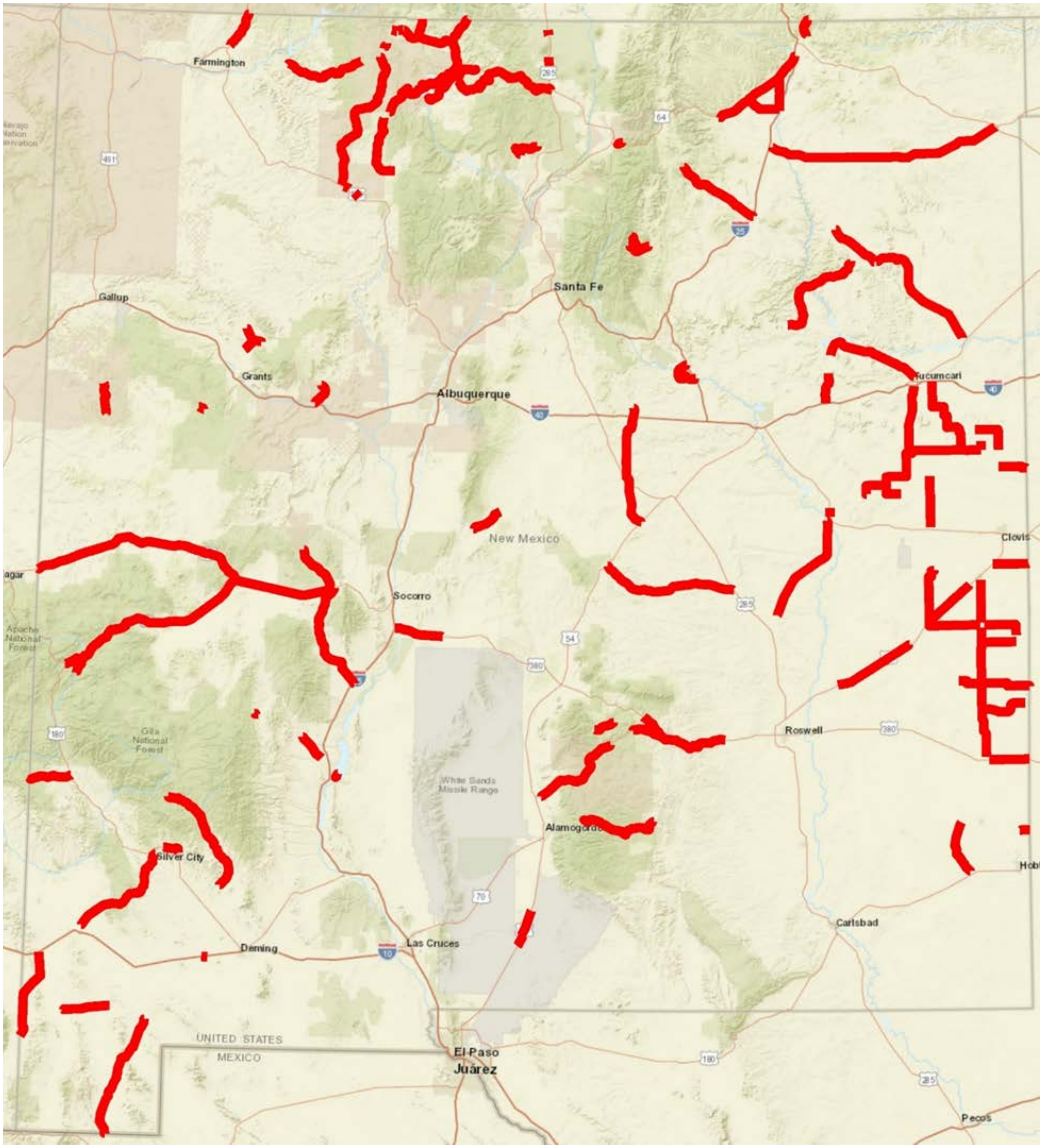

Figure 2. Highways in New Mexico where at least 50% of crashes are WVCs.

In addition to direct collisions with wildlife, it is common for vehicles to swerve to avoid a WVC and collide with another vehicle or a roadside object *(6)*. Anecdotal evidence says that these types of collisions are common, although this characteristic is not reported, making it difficult to track. Accordingly, these types of crashes are not included in the previous analysis and often go unaccounted for.

Not only is the safety of human users of the roadway important, but ensuring continuous wildlife migration corridors has been identified as a priority in New Mexico. New Mexico Governor Michelle Lujan Grisham signed the Wildlife Corridors Act into law in March 2019. This act tasks the NMDGF and NMDOT with developing an action plan to ensure safe migration of wildlife by identifying key barriers and providing animal passage opportunities across those barriers. A multi-state pooled fund study organized by several western states exploring WVC mitigation effectiveness has also identified wildlife passage as a pressing issue. With past research finding upwards of 10,000 animal fatalities at a single monitoring site over a 17-month period, WVCs can have vital impacts on wildlife habitats, migration, and survival *(7)*.

To avoid WVCs, roadway engineers have two choices: 1) warn motorists of the presence of wildlife on the roadway or 2) provide wildlife with a way to avoid entering the travel way *(8, 9)*. To achieve the former, methods of detecting wildlife and warning motorists must be utilized. We focus on the more-popular latter approach, for which a variety of wildlife crossing structures are typically used. These structures include wildlife underpasses, multi-use underpasses, culverts, landscape bridges, wildlife overpasses, and multi-use overpasses. To ensure that wildlife utilize these crossing structures, crossing designs typically include game fencing to channel wildlife to the crossing.

NMDOT has designed and constructed WVC mitigation projects since 2004 and seeks to answer a number of important questions that they have encountered in so doing. How much game fencing is needed to effectively direct wildlife to a crossing structure? Currently, only one study provides guidance regarding this question, and those findings are presented as broad recommendations of greater than 5 km for all species of wildlife *(10)*. However, past work by NMDOT has found that some species of deer will avoid underpasses, instead walking around or jumping the game fence. With a variety of crossing structures available and a variety of animals of different species, ages, and genders needing to use the structures, the question of how to best direct wildlife to different crossing structures requires further investigation.

What size underpasses will elk and other species use? Elk are an important species in the New Mexico ecosystem and ensuring their safe movement is a primary concern. Furthermore, elk WVCs are especially harmful. However, elk have been shown to be hesitant to utilize small crossing structures. This research seeks to better understand this vital question.

What types of rare animals use the facilities and the corridor? While deer and elk crossings are frequent and their WVCs inflict the most damage, we wish to understand the range of animals that use this migration corridor and depend on the crossings. Gaining a fuller understanding of what wildlife habitats and migration patterns are disrupted by the transportation system is an important part of this project.

What is the best way of monitoring wildlife to explore the above questions? We must monitor large and small species at night and during adverse weather conditions while avoiding vandalism and theft of our equipment. To optimize this complicated process, new technologies will be investigated and novel installation techniques will be developed. A lack of research exists regarding all the above research questions and therefore requires further investigation.

This work will explore the effectiveness of two crossings, thereby contributing to and leveraging the knowledge gained at several other crossings through three larger projects: 1) an on-going collaboration between NMDOT and AZGFD exploring WVC mitigation effectiveness, which is currently entering Phase 2; 2) a multi-state pooled fund study organized by several western states exploring WVC mitigation effectiveness; and 3) the state Wildlife Corridors Act, SB228, focused on WVC mitigation, which was recently passed through the New Mexico legislature. Lessons learned through this project will help advance the efforts mentioned above and develop our understanding of WVCs, contributing to our goal of saving lives (both human and wildlife) and enhancing wildlife conservation efforts.

2. OBJECTIVES

The overall purpose of this project is to develop cost-effective solutions to WVCs and share those lessons nationwide to save lives (both human and wildlife) and enhance wildlife conservation efforts. To accomplish this overall purpose and to answer the above research questions, the research team will examine two wildlife crossing underpasses located near Lumberton, New Mexico (Figure 3) and split the project into two specific objectives. The first objective is to develop enhanced monitoring techniques. Novel wildlife detection technologies – including Reconyx HP2X HyperFire 2 professional covert infrared cameras – will allow us to understand how much and what type of wildlife are utilizing the underpasses and how we might better channel animals to the crossings. The cameras will be fixed with special mounting brackets that are developed and fabricated to allow for the installation of monitoring equipment while avoiding vandalism and theft. We will place these cameras strategically at the monitoring sites, enabling us to determine whether different species, ages, and genders of wildlife are only approaching or actually utilizing the underpasses.

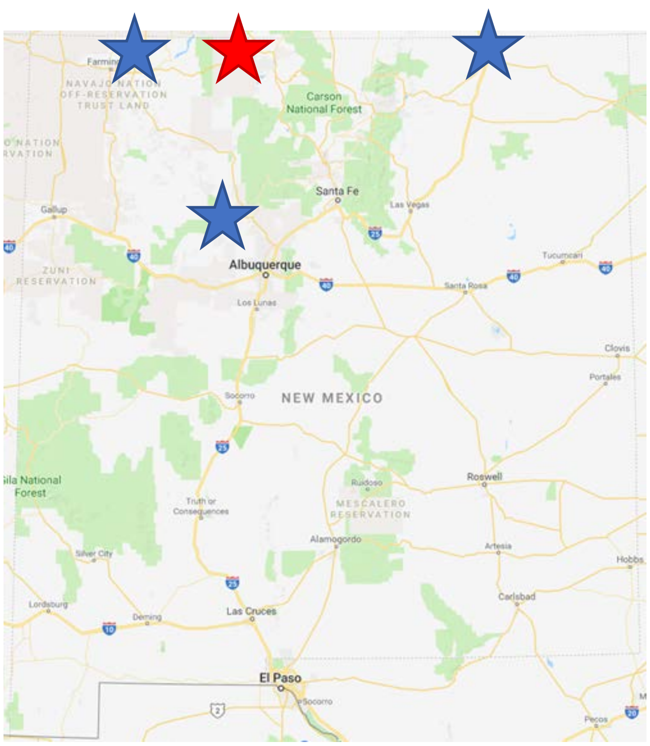

Figure 3. Project location near Lumberton, New Mexico on US 64 (red star) and existing monitoring stations (blue stars).

The second objective of the work is to analyze the wildlife observations that are collected. This will help us to understand the effectiveness of the fencing, which species use which crossings, what time of year and day are wildlife using the crossings, and information pertinent to our other research questions. Although only seven months of data were collected at the time of this report, we provide a preliminary analysis of observations and will provide an entire 12-month analysis for the following Implementation Report. Observations are supplemented with WVC counts to better understand WVC-mitigation effectiveness.

3. LITERATURE REVIEW

A variety of approaches have been employed to prevent WVCs. These approaches include limiting wildlife populations, offering food to entice wildlife to behave in a certain manor, frightening wildlife from the roadside, and reducing the number of motor vehicles. Past research has found that these approaches are either not effective at reducing WVC prevalence or are otherwise not feasible or ethical solutions *(11)*. For example, limiting motor vehicles and wildlife populations go against the goal of ensuring the safe coexistence of transportation networks and wildlife migrations.

To reduce WVCs, research has found that roadway engineers have two effective choices: 1) warn motorists of the presence of wildlife on the roadway or 2) allow wildlife to avoid entering the roadway via overpasses or underpasses. Of the two choices, overpasses or underpasses have been shown to be the most effective engineered solution for reducing WVCs *(10, 11)*. Studies have shown that such approaches can reduce large mammal-vehicle collisions by 80-97% *(12-14)*. Accordingly, the overpass/underpass approach is the most popular and a variety of wildlife crossing structures have been developed for the purpose.

3.1. What Kind of Crossing Structures Are Available?

Wildlife-crossing structures include wildlife underpasses, multi-use underpasses, culverts, landscape bridges, wildlife overpasses, and multi-use overpasses (Figure 4) *(15)*. Because there are few before-and-after studies for the installation of wildlife-crossing structures, their effectiveness is not yet completely clear *(15)*. Effectiveness is often based on anecdotal evidence and because poor designs will do little to prevent WVCs, selecting the correct crossing structure for a site's landscape and wildlife is integral *(16)*. The location of a crossing has been found to be the most important factor impacting effectiveness *(17-22)*.

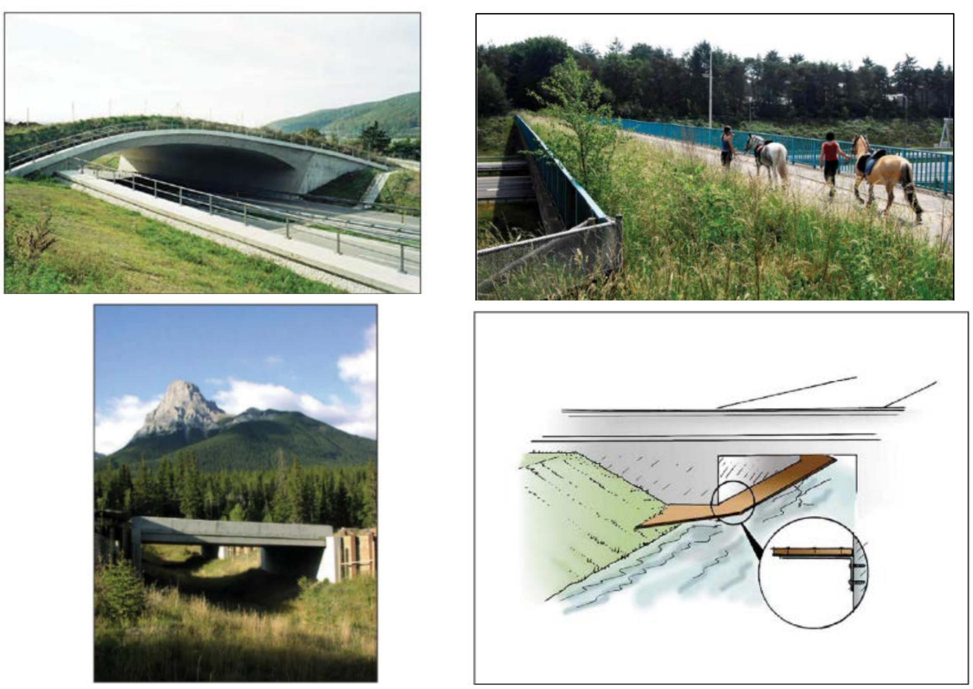

Figure 4. Examples of wildlife crossings (clockwise from top left): landscape bridge, multiuse overpass, modified culvert, and large mammal underpass. (*Source: Clevenger and Huijser 2011*)

Culverts are typically smaller structures made of concrete, smooth steel, or corrugated metal. Box culverts are usually larger than pipe culverts *(15)*. These facilities are suitable for amphibians, reptiles, and some smaller mammals and have been found to reduce wildlife mortality by 93.5% for these species *(23)*. Culvert crossings on the Trans-Canada Highway were found to be used by 2.8 species each *(24)*. Because culvert crossings are relatively small, they are economical solutions. However, they only work for smaller animals and may experience blockage, especially if used for water conveyance. For our project, we expect to be concerned with larger mammals – such as deer and elk – that would likely not use this form of crossing.

Overpasses are the most expensive crossing solution, but they can also accommodate the largest variety of wildlife species because they are less confined, quieter, and better blend in with the surrounding environment *(15)*. Wildlife overpasses can be designed exclusively for wildlife or can be used by both wildlife and humans (a.k.a. multi-use overpasses or bridges). Overpasses typically range from 100 to 650 feet wide at the mouths but may narrow in the middle. This narrowing may impact usage *(16, 25)*. While large mammals such as deer have been found to frequent overpasses, they take time to habituate to the crossings *(26)*.

Wildlife underpasses can accommodate large animals (but possibly not to the extent of overpasses) and may be integrated into existing bridge structures. Underpasses are more expensive than culverts but may be used by a wider variety of animals and are not susceptible to blockage. Because bridge underpasses are often found in conjunction with water, these crossings can be especially attractive to wildlife. Veenbaas and Brandjes investigated underpasses underneath highways in the Netherlands, finding that broader underpasses were more heavily used by mammals *(27)*. There was no such relationship for amphibians. They found that mammals used all studied underpasses that were along a waterway, while only 75% of such underpasses were used by amphibian species.

NMDOT, NMDGF, and AZGFD have been monitoring eleven crossing sites in New Mexico located near the towns of Aztec, Cuba, and Raton (blue stars in Figure 3). These crossings structures include ten underpasses and one overpass (Table 1). Seven of the underpasses are concrete box culverts (CBC) and three are bridges. The one overpass is a multi-use bridge. All of these crossing facilities utilize existing structures. The culvert underpasses range in height from 6.9 feet to 15.7 feet. The bridge underpasses range in height from 15.7 feet to 38.1 feet. The culvert underpasses range in width from 3.9 feet to 20.0 feet. The bridge underpasses range in width from 39.0 feet to 69.6 feet. All these studied crossings have been effective, but not all have elk present. Our project also examines existing bridge underpass crossings.

Table 1. Existing wildlife crossing monitoring site characteristics (in meters).

Site	Roadway	Milepost	Structure	Common Name	Crossing Type	Height	Width	Length	Openness Factor	Human Use
RATON	I-25	452.5	CBC	Raton Creek	Below-grade	4.2	4.2	45.5	0.40	MODERATE
RATON	I-25	453.8	Bridge	Lincoln Bridge	Below-grade	4.8	11.9	31.5	1.80	HIGH
RATON	I-25	454.0	Bridge	First St. Bridge	Above grade	5.2	9.0	60.9	N/A	HIGH
RATON	I-25	454.2	CBC	Unnamed Culvert	Below-grade	2.4	2.4	38.1	0.15	LOW
RATON	I-25	458.1	CBC	Culvert	Below-grade	2.1	1.2	55.6	0.05	NONE
RATON	I-25	458.9	CBC	Culvert	Below-grade	2.4	3.6	96.4	0.09	NONE
AZTEC	US 550	170.1	CBC	Culvert 1	Below-grade	4.8	6.1	36.7	0.80	HIGH
AZTEC	US 550	171.1	CBC	Culvert 2	Below-grade	4.8	6.1	37.8	0.78	LOW
AZTEC	US 550	172.8	CBC	Culvert 3	Below-grade	4.8	3.6	27.9	0.63	MODERATE
CUBA	US 550	52.7	Bridge	S. Rio Puerco	Below-grade	11.6	21.2	61.2	4.03	LOW
CUBA	US 550	53.7	Bridge	N. Rio Puerco	Below-grade	9.5	21.2	86.7	2.31	LOW

3.2. How Much Fencing Is Necessary?

Using fencing or other barrier walls in conjunction with crossing structures has been shown to effectively prevent wildlife access to roadways and lower WVCs *(23, 25, 28-32)*. Game fencing is typically 8-feet high and channels wildlife to the structure. While research has shown that the installation of fencing can reduce WVCs, there has been limited research examining the length of fencing needed to successfully route wildlife toward a crossing structure *(12)*. Due to economic and aesthetic reasons – and because wildlife can be hurt by fencing – there is a desire to minimize the amount of fencing used *(10)*. However, the amount of fencing installed with a crossing structure has been shown to impact the usage and efficiency of the structure as WVCs tend to concentrate near fence ends *(10, 12)*. Strategically placing the right amount of fencing can have a large impact on the effectiveness of a crossing system.

The lone piece of research that ventures to recommend fencing lengths states that crossing structures with short lengths of fencing (<5 km) were found to have lower and more variable effectiveness than those with long fencing (>5 km) *(10)*. These meta-analysis results, however, were collated for a wide variety of wildlife (large mammals the size of a deer or larger) in a specific geographic context of Montana. They were also collated for underpasses with dimensions suitable for large mammals. In their study, 94.37% of crossings were by white-tailed deer, 3.42% by mule deer, 1.55% by American black bear, 0.33% by mountain lion, 0.26% by unidentified deer species, 0.05% by grizzly bear, 0.01% by elk, and 0.01% by unidentified bear species. As white-tailed deer are rare in New Mexico and elk are prevalent at our study location (detailed in Section 3.3.), further research is needed to explore this question in terms of different species, genders, and ages of wildlife, types of crossings, and geographic contexts. More research is needed to better understand how much game fencing will effectively funnel wildlife to the desired crossing facilities.

3.3. What Species of Wildlife Will Use the Crossings?

The existing NMDOT monitoring sites at Aztec, Cuba, and Raton will inform us regarding what types of species we can expect at the study site near Lumberton. Monitoring at the existing sites has resulted in 739,421 images of wildlife between February 2017 and June 2018. The most frequent species at these sites have been mule deer (*Odocoileus hemionus*). Over 5,000 mule deer were recorded during the 17 months studied. The next most frequent species is elk (*Cervus canadensis*) with 127 recorded at a single location (Cuba), which is south of the Dulce site but along the same corridor. No elk were recorded at the other sites. Other medium-sized mammals including coyote (*Canis latrans*), fox (*Chordata* spp.), bobcat (*Lynx rufus*), black bears (*Ursus americanus*) are frequent visitors in this region of New Mexico, with 131, 103, 82, and 71 animals counted across the three sites, respectively. Small mammals such as jackrabbit (*Lepus* spp.), rock squirrel (*Otospermophilus variegatus*), and skunk (*Mephitidae* spp.) are recorded less frequently, with less than twenty of each species across all sites. The rarest animals were mountain lion (*Puma concolor*), pronghorn (*Antilocapra americana*), and beaver (*Castor* spp.) with 7, 1, and 1 observed, respectively, across all sites.

The most important animal to monitor for our project may be the deer and elk, which are numerous in the region, have significant migration routes, and account for much WVC damage. Ensuring that we account for these species will allow us to answer our first two research questions regarding fencing and whether elk will use both crossings. Monitoring the other species will allow us to answer our third research question regarding rare animals.

3.4. What Time of Day Will Wildlife Use the Crossings?

The animals that we expect to encounter at the study site are primarily nocturnal. The three existing monitoring sites in the region have detected the majority of their wildlife occurrences in the dark (Figure 5). Therefore, we need detection equipment that can effectively function at night. There are two types of flashes that we may consider for nighttime detection on our monitoring equipment: visible light and infrared. A visible light flash will be visible to the wildlife and can scare them, meaning that visible light flashes are a relatively invasive method of nighttime detection. We therefore prefer infrared flashes for our monitoring equipment to noninvasively monitor frequent nighttime movements.

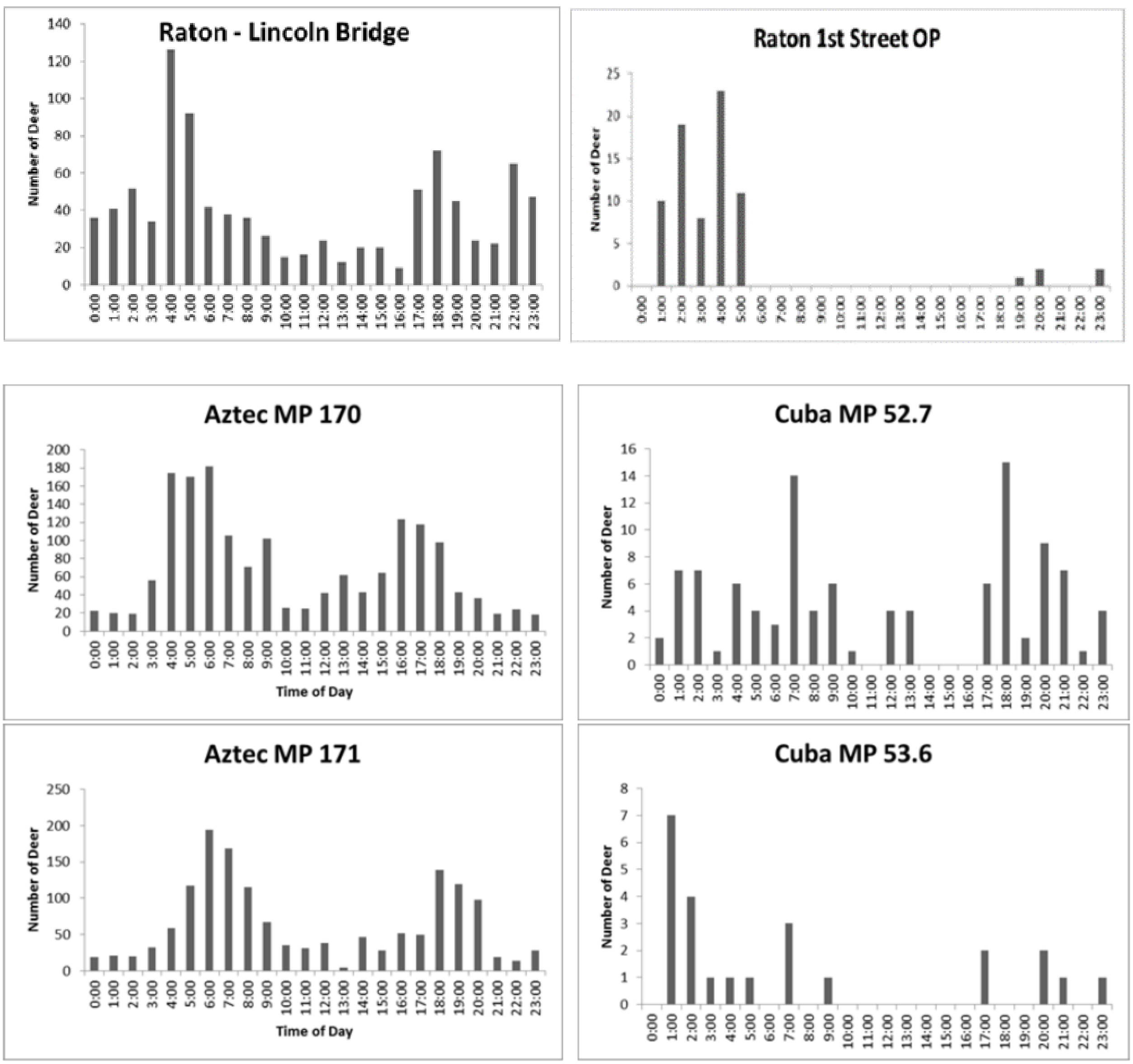

Figure 5. Time of day of mule deer detections at existing monitoring sites.

3.5. What Seasons Will Wildlife Use the Crossings?

Wildlife activity is highest in the spring for the three existing monitoring sites in the region (Figure 6). We expect the study site to have similar characteristics. However, there is also significant wildlife activity during the winter months. Furthermore, the crossing facilities that we will be studying are located at high elevation at the southern end of the Rocky Mountain range. We must therefore ensure that the detection equipment that we select will be able to function in extreme weather conditions. Therefore, a key consideration is battery performance and life. We prefer to use monitoring equipment that can utilize lithium batteries as opposed to alkaline batteries. Lithium batteries will function down to -40 degrees Fahrenheit and should last up to two years regardless of weather conditions.

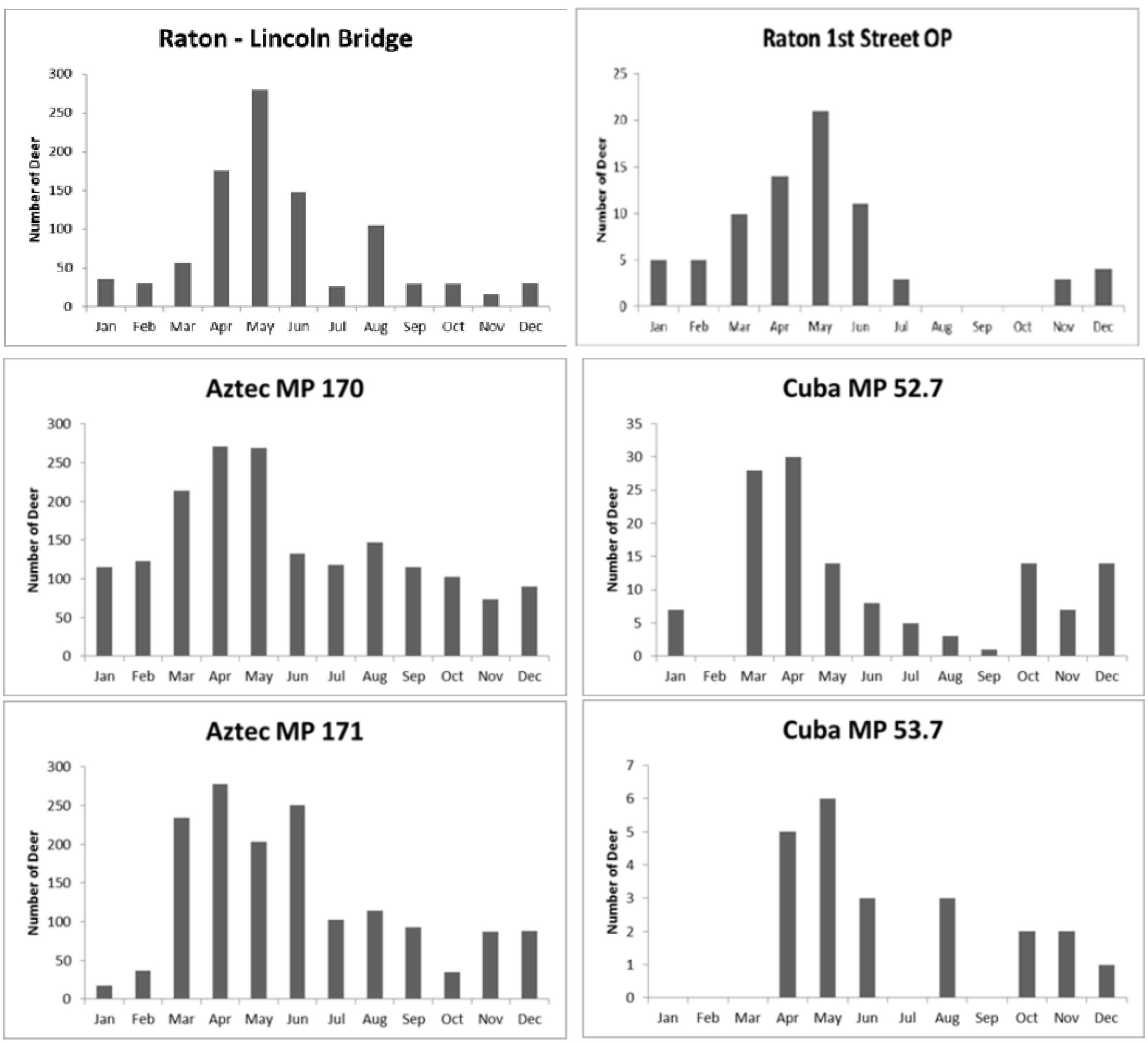

Figure 6. Month of the year of mule deer detections at existing monitoring sites.

3.6. How to Detect and Monitor Wildlife?

To understand which overpasses and underpasses work and for which species, we must track the wildlife. Wildlife has been tracked for millennia, often using tracks and scat *(17, 33)*. Veenbaas and Brandjes used sandbeds and ink paper at a variety of crossings structures to gather tracks and then analyze wildlife movements *(27)*. Other research has collected and analyzed the location of animal scat to track wildlife movements *(34, 35)*. However, these methods are not considered cost-effective, requiring frequent visits by highly-trained wildlife experts, and are still prone to undercounting wildlife.

Digital wildlife detection and recording systems are a relatively recent innovation, and several different detection methods have been tested by prior research. These detection methods include Doppler microwave radar, break-the-beam sensors, and seismic sensors *(36, 37)*. However, these approaches do not allow for the identification of wildlife species, age, and gender, and the Federal Highway Administration (FHWA) still considers these wildlife detection systems experimental and are cost-prohibitive.

Tracking wildlife through motion-activated cameras has been found to be one of the most noninvasive methods because of limited human intervention *(38)*. This method is also cost-effective and allows for the identification of species, age, and gender of the wildlife through photo identification. It is only necessary to be on site once every few weeks or months to collect the data that is stored electronically in the device. Deer have been found to be significantly more likely to be tracked by motion-activated camera than by other methods such as observing animal tracks *(38)*. Such detection equipment will be important in helping us determine how much fencing is necessary at our site.

While there are several brands of wildlife camera traps, Reconyx is a leader in the field and their products are frequently used successfully in research *(10, 39-44)*. The latest version of Reconyx wildlife camera traps is the HP2X HyperFire 2 Professional Covert Infrared Camera (Figure 7). This camera uses motion-detection bands instead of a cone of detection and detects both movement and changes in temperature of bodies in the field of vision. Range is approximately 40 feet and the cameras are set to trigger when both motion and a difference in temperature are detected. For nighttime tracking, the flash can be visible light or infrared. A trigger can result in a single photograph, a set of three photographs, or a video, depending on the preferred output. The cameras use SD memory cards and lithium AA batteries that can withstand extreme conditions in the field.

Figure 7. Reconyx HP2X HyperFire 2 professional covert infrared camera.

Reconyx wildlife camera traps have been tested by past researchers and have been shown to be effective, but not perfect. Urbanek et al. found that the Passive Infrared Motion Detector setting – a setting that uses an electronic sensor to measure infrared light radiating from objects in its vision field – only detected approximately 84-86% of bears (*Ursus americanus*), coyotes (*Canis latrans*), bobcats (*Lynx rufus*), and red wolves (*C. rufus*) in a study performed in North Carolina *(45)*. The cameras were found to be unreliable for smaller species such as rabbits and squirrels. However, these smaller species will not be of concern for our project as they are not a significant contributor to costly WVCs. The cameras have been found to be effective for larger species and are used at three other existing New Mexico monitoring sites.

3.7. What Outcomes Will We Measure?

There are several ways to measure the effectiveness of wildlife crossing facilities. Because the goal of this project is to mitigate WVCs while ensuring safe wildlife passage, we will measure two types of outcomes: WVCs and passages. Measuring WVCs directly will provide us with important information. However, researchers can also count carcasses that are on the side of the road as road-kill as a WVC proxy. Because not all WVCs are reported and therefore might not end up in our collision data, carcass counts can further inform the number of WVCs that occurred. In addition to direct measures of WVCs, we will also monitor and count approaches and passages at the crossing structures themselves.

We will utilize NMDOT crash layers in a geographic information system (GIS) to understand how many WVCs are occurring and if crossing structures and game fencing have been effective at reducing their prevalence. This data is available for the previous decade, providing an opportunity for a longitudinal analysis. We also expect to receive vehicle volume data from NMDOT so that we can account for exposure and better understand WVC rates.

Carcass counts have been used by researchers in the past *(46-49)*. This method may only be effective for larger animals because of carcass persistence time and detectability. Smaller animals such as squirrels, rabbits, and foxes most likely will be removed by other scavengers *(49)*, with some researchers estimating overall carcass persistence time at one day *(47)*. This lack of persistence time may also be an issue with carcasses of larger animals. In terms of detectability, smaller animals may not get picked up by maintenance crews and will therefore not be reported. This means that carcass counts often underrepresent actual WVCs. Teixeira et al. estimated that carcass counts underestimate actual WVCs by 12-16 times for small animals while Santos et al. estimated that carcass counts underestimate actual WVCs by 2-10 times for all animals *(47, 49)*.

With our wildlife detection equipment, we will monitor both the approaches of wildlife as well as the passage rates at the different crossing structures. This is important because some wildlife species (primarily elk) may approach smaller underpasses, but turn around and not actually use the structure. Because we have positioned our cameras to capture both the animals that approach the structures and animals that pass through the structures, we will be able to understand both approach and passage rates for different species.

4. METHODOLOGY

We monitored two wildlife crossings along US 64 in northern New Mexico (Figure 8). Both crossings are US 64 highway bridges over Amargo Creek. The bridges are approximately five miles east of Lumberton, NM, the closest census-designated place, and are located between Dulce, NM to the west and Chama, NM to the east. The study site is located approximately five miles south of the Colorado state line. Both crossings are in NMDOT District 5.

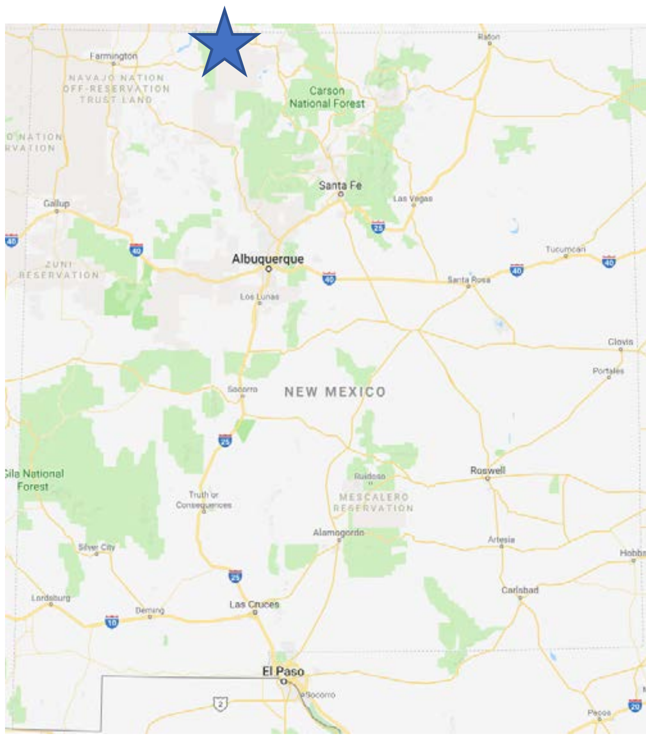

Figure 8. Project location.

The monitoring site is in a high desert or mountainous landscape, located at the southern end of the Rocky Mountains at approximately 7,300 feet elevation. There is abundant wildlife in the area and the Amargo Creek passages are known crossings for that wildlife. Accordingly, wildlife fencing was installed on the study corridor in 2012. According to NMDOT data, there were eleven reported WVCs in the eight years before the wildlife fencing installation, accounting for approximately 50% of reported motor vehicle crashes.

The fencing covers a stretch of roadway with topography that results in poor roadside visibility, where it is therefore important to control the location of wildlife crossings. The fencing extends approximately 2.7 miles between the crossing locations (Figure 9). The northern bridge is #9387 at mile post (MP) 142.1 (coordinates of 36.932561, -106.886950) and the southern bridge is #9415 at MP 144.8 (coordinates of 36.903514, -106.855331). The landscape transitions to sagebrush flats to the west, allowing for more roadside visibility and alleviating the need for fencing further west. The landscape becomes more mountainous to the east, precluding wildlife crossings.

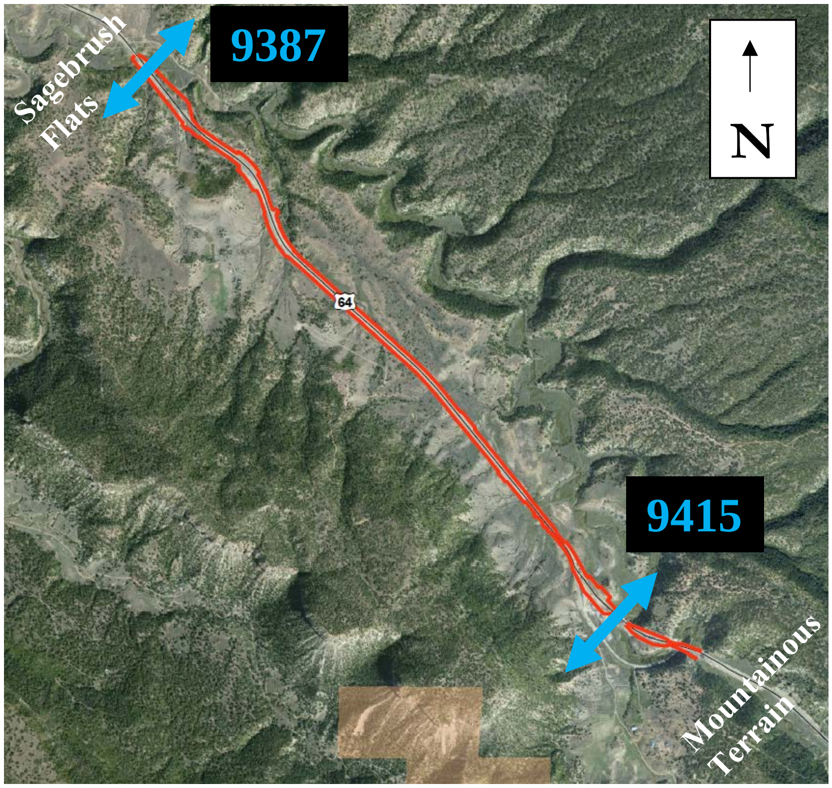

Figure 9. Crossing locations (blue arrows) and location of game fencing (in red).

Bridge #9387 is smaller at 109.9 feet long and 41.0 feet wide curb-to-curb with approximately 20 feet of clearance underneath (Figure 10). Bridge #9415 is 309.7 feet long and 42.0 feet wide curb-to-curb with approximately 40 feet of clearance underneath. Bridge #9387 was constructed in 2008 and #9415 in 2013. Both bridges are two lanes wide and carry less than 3,000 annual average daily traffic (AADT).

Figure 10. Bridge #9387 (left) and bridge #9415 (right).

Four monitoring cameras were installed at each bridge, resulting in eight cameras total. Seven of the cameras were affixed to steel poles installed under the bridges. One camera was installed directly onto a bridge pier. The steel poles were 2.5 inches in diameter and schedule 40. Two feet of each pole was secured in a concrete footer, leaving ten feet of each pole exposed above ground (Figure 11).

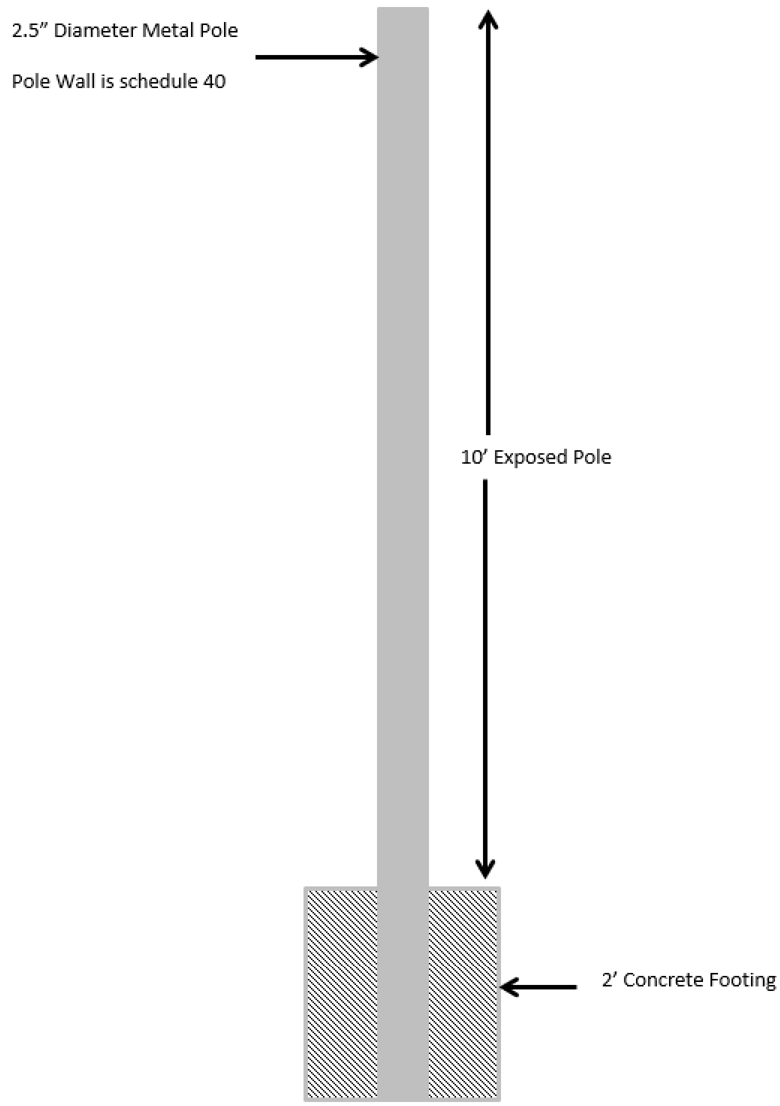

Figure 11. Pole installation schematic.

4.1. Bridge #9387

To coincide with wildlife movements, one pole was installed in the center (in terms of both length and width) of bridge #9387 (see red circle in Figure 12). Four cameras were installed onto the pole to record wildlife approaches and passages in each direction (see red arrows in Figure 12). This coverage of all directions allowed us to determine both approaches and passage rates of wildlife.

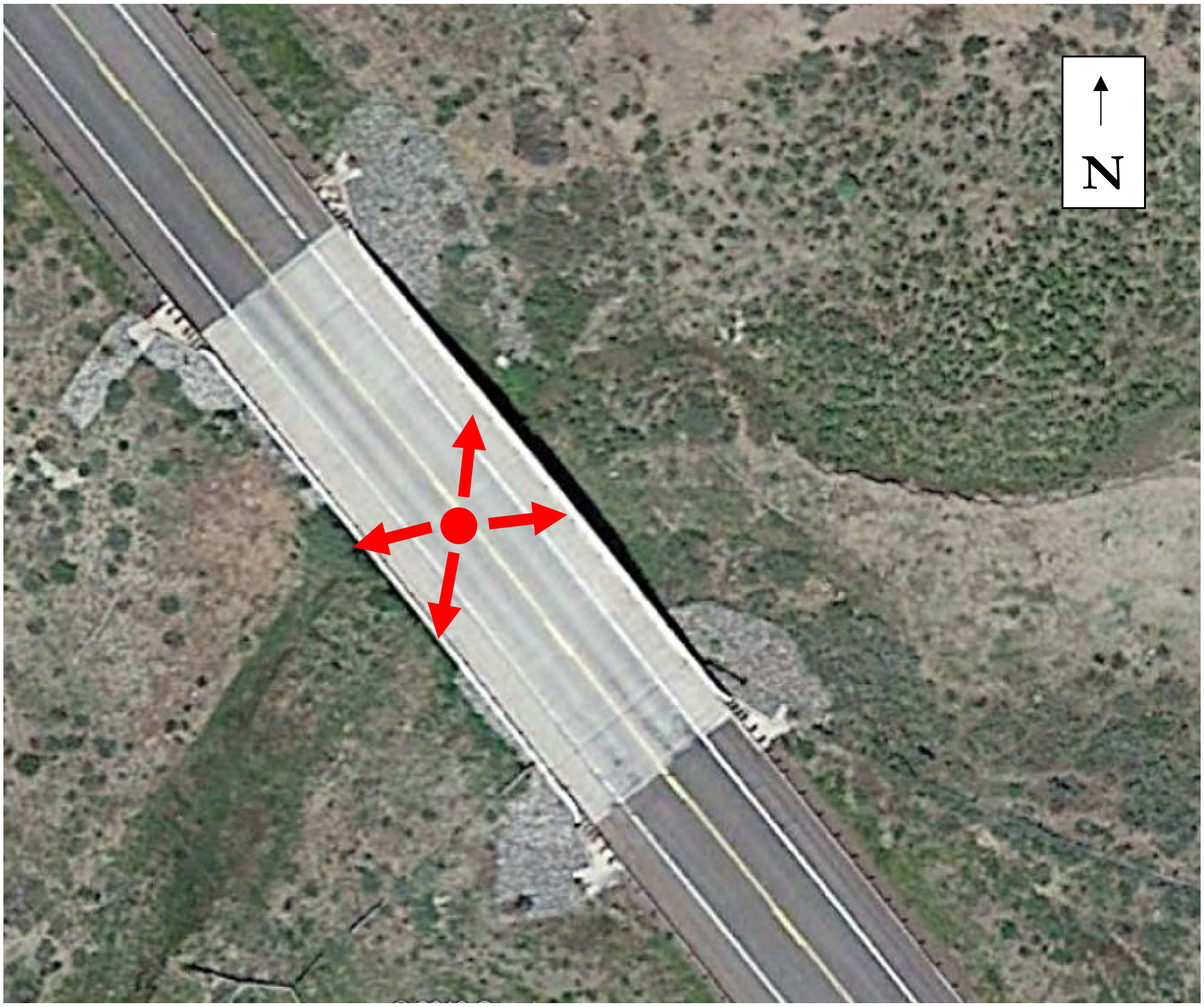

Figure 12. Pole installation (red circle) at bridge #9387 and four camera directions (red arrows).

While bridge #9387's structure is 109.9 feet long, there are steep slopes with riprap on either end of the bridge. The actual area that wildlife can use is approximately 45 feet wide. Amargo Creek flows on the northwest end of bridge #9387. The pole was installed approximately 15 feet southeast of the creek (Figure 13). Amargo Creek is typically frozen for several months each year and is occasionally dry. Wildlife use the creek itself for passage when these conditions exist. The cameras were installed with enough height and were angled down to monitor the creek bed itself. There is also a heavily used wildlife trail on the south end of the bridge. The positioning of the four cameras allowed us to capture both of these movements. Vegetation was thinned within 40' of the pole to prevent camera false captures.

Figure 13. Pole installation at bridge #9387 looking north with Amargo Creek visible to the left of the pole.

4.2. Bridge #9415

There is substantial riprap in the middle of bridge #9415, preventing wildlife through movements underneath the center of the bridge (Figure 14). Amargo Creek runs underneath the southeast side of the bridge but has fencing for cattle and sharp banks, precluding wildlife through movements on the southeast side. We therefore monitored the primary through-movement on the northwest side of bridge #9415 and approaches in the middle and the southeast end of the bridge.

To coincide with primary wildlife movements, one pole was installed underneath the northwest span of bridge #9415 (pole A in Figures 14-16) and one pole underneath the middle span of the bridge (pole B in Figures 14-16). Two cameras were installed on pole A and one camera was installed on pole B (red arrows in Figure 14). To coincide with secondary wildlife movements, one camera was installed on a bridge pier on the southeast side of the bridge (see blue circles in Figures 14-16). All these installations are inside the drip line of the bridge. Vegetation was thinned within 40’ of each camera to prevent camera false captures.

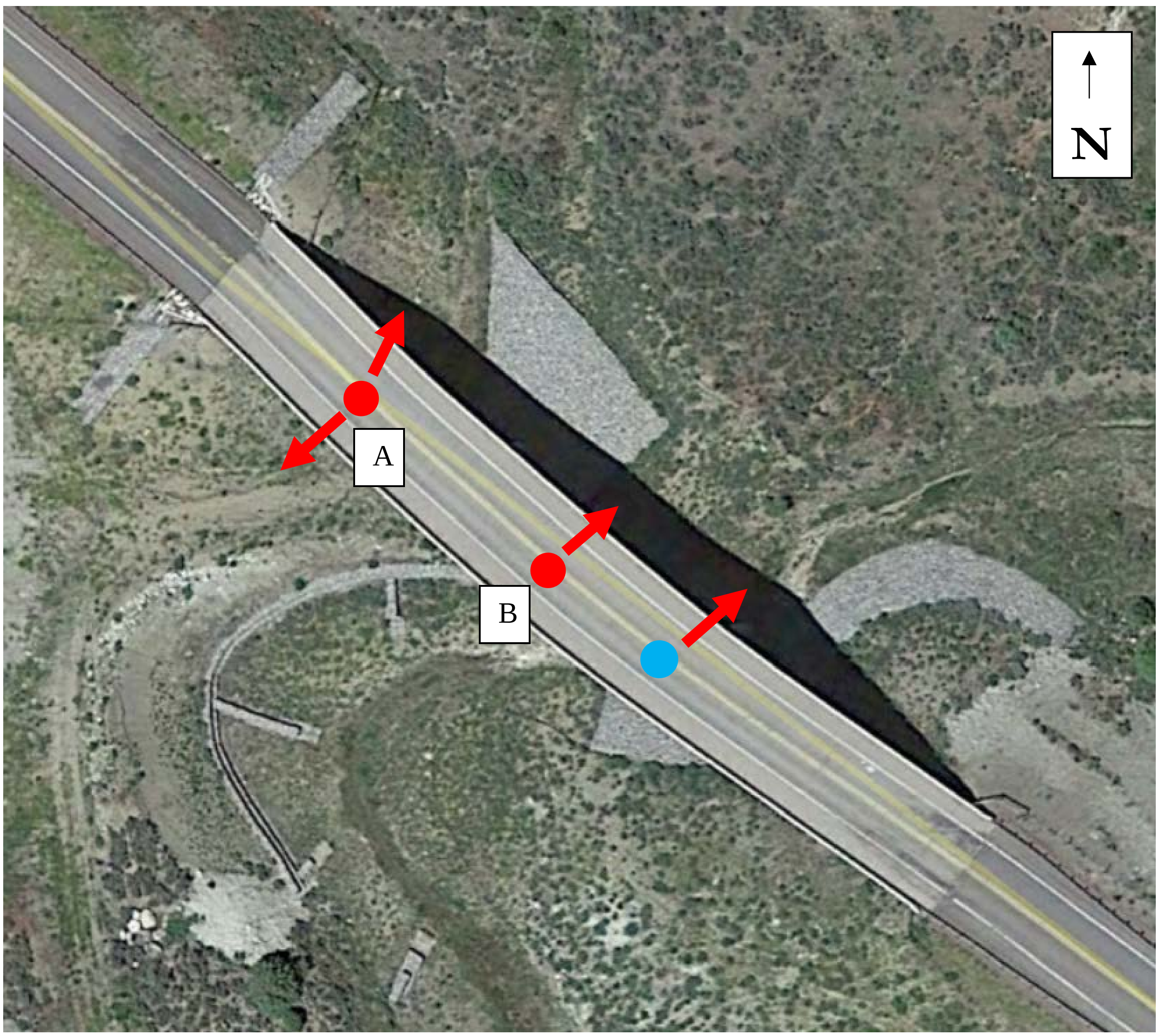

Figure 14. Pole (red circles) and pier (blue circle) installations at Bridge #9415 and four camera directions (red arrows).

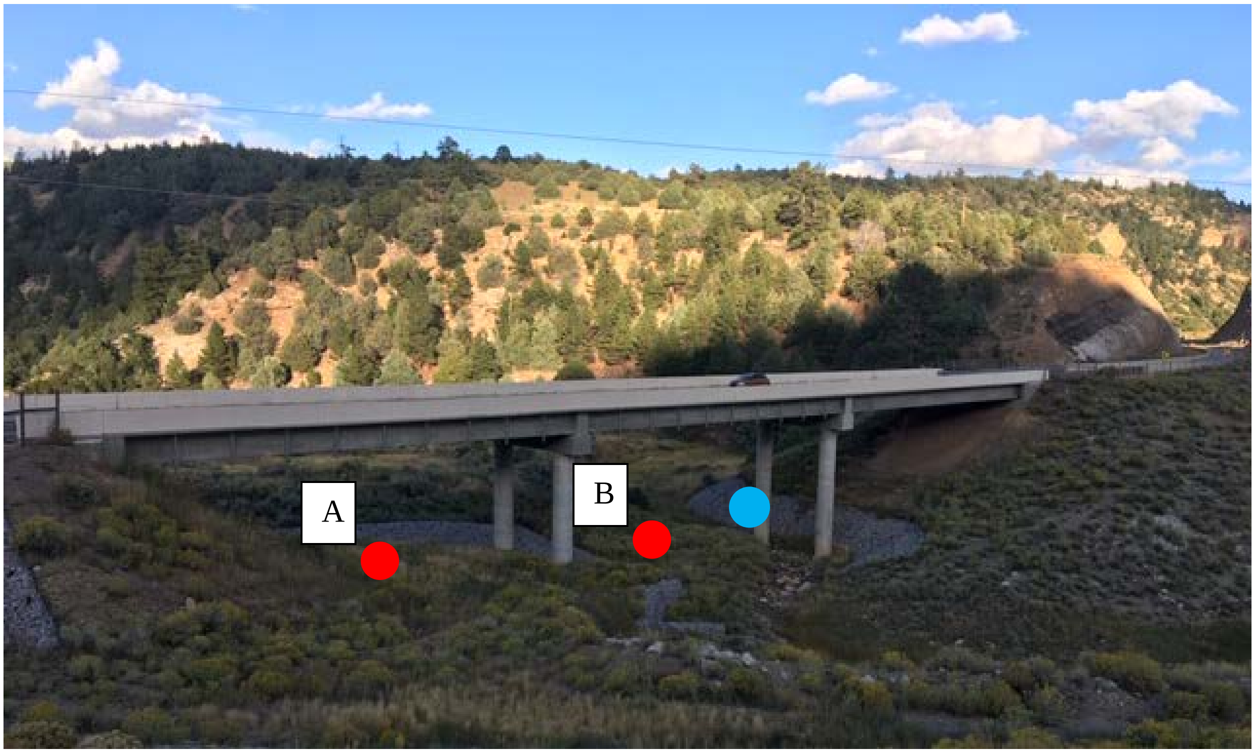

Figure 15. Pole installations (red circles) and pier installation (blue circle) at Bridge #9415, looking north.

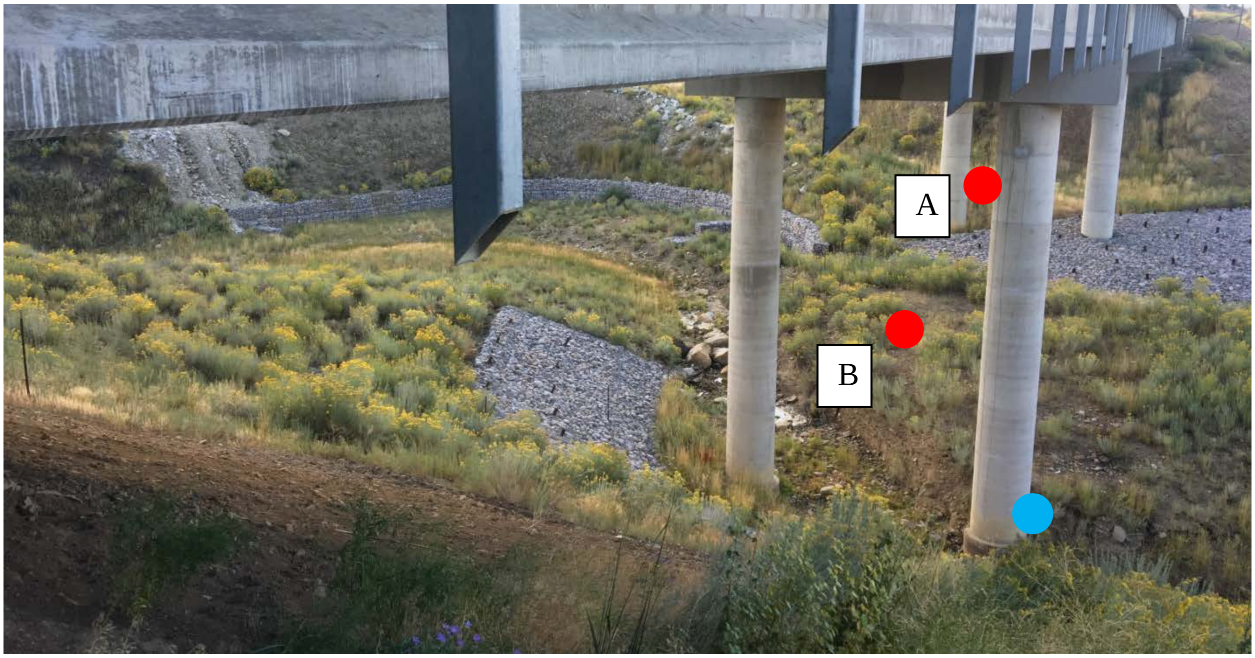

Figure 16. Pole installations (red circles) and pier installation (blue circle) at Bridge #9415, looking south.

The two cameras on pole A (Figure 17) and the one camera on pole B (Figure 18) were installed at approximately 5 feet in height, allowing them to capture small and large wildlife. The camera on the pier (Figure 19) is installed approximately 7 feet above the creek bed. The camera is angled slightly downward so that it can monitor activity in the creek in addition to approaches. The bracket for the pier camera was bolted directly to the pier.

Figure 17. Pole A installation, looking east.

Figure 18. Pole B installation, looking west (pole A in the background to the left of the right-most pier).

Figure 19. Pier installation.

To avoid vandalism and theft, the cameras were locked into steel enclosures, the enclosures were fixed onto mounts, and the mounts were secured to the poles (Figure 20). The steel enclosures were purchased from the camera manufacturer and were designed to securely hold the camera without obstructing the sensors or the recording device itself. The enclosure had a faceplate that can be removed to access the camera and can be locked when in use. We used keyed locks with protected shanks.

The enclosure is secured to the mount with bolts and nuts. The nuts are inside the enclosure so that they can only be removed if someone has access to the inside of the enclosure. The mounts allow for vertical and horizontal adjustments of the cameras (Figure 21). The vertical pivot is made around a bolt that has two nuts. The inside nut can be loosened to allow for adjustment of the mount and then tightened to secure the mount. The outside nut is welded to the end of the bolt so the inside nut cannot be removed, precluding disassembly of the mount. The horizontal pivot is made around a bolt that has one nut and a hole drilled in the end of the bolt. The nut can be loosened to allow for adjustment of the mount and then tightened to secure the mount. The hole at the end of the bolt allows for a padlock to be locked to it, precluding the removal of the nut or disassembly of the mount. The mounts were custom designed with help from AZGFD. The mounts were built by a steel fabrication shop in Albuquerque. To attach the camera mount to the pole, we used 7/16-14 bolts (2 per mount) after we drilled and tapped holes in the poles. The bolts are inside the mount and can only be accessed if the padlock on the horizontal-pivot adjustment bolt is removed and the front end of the entire mount is detached.

Figure 20. Camera installation.

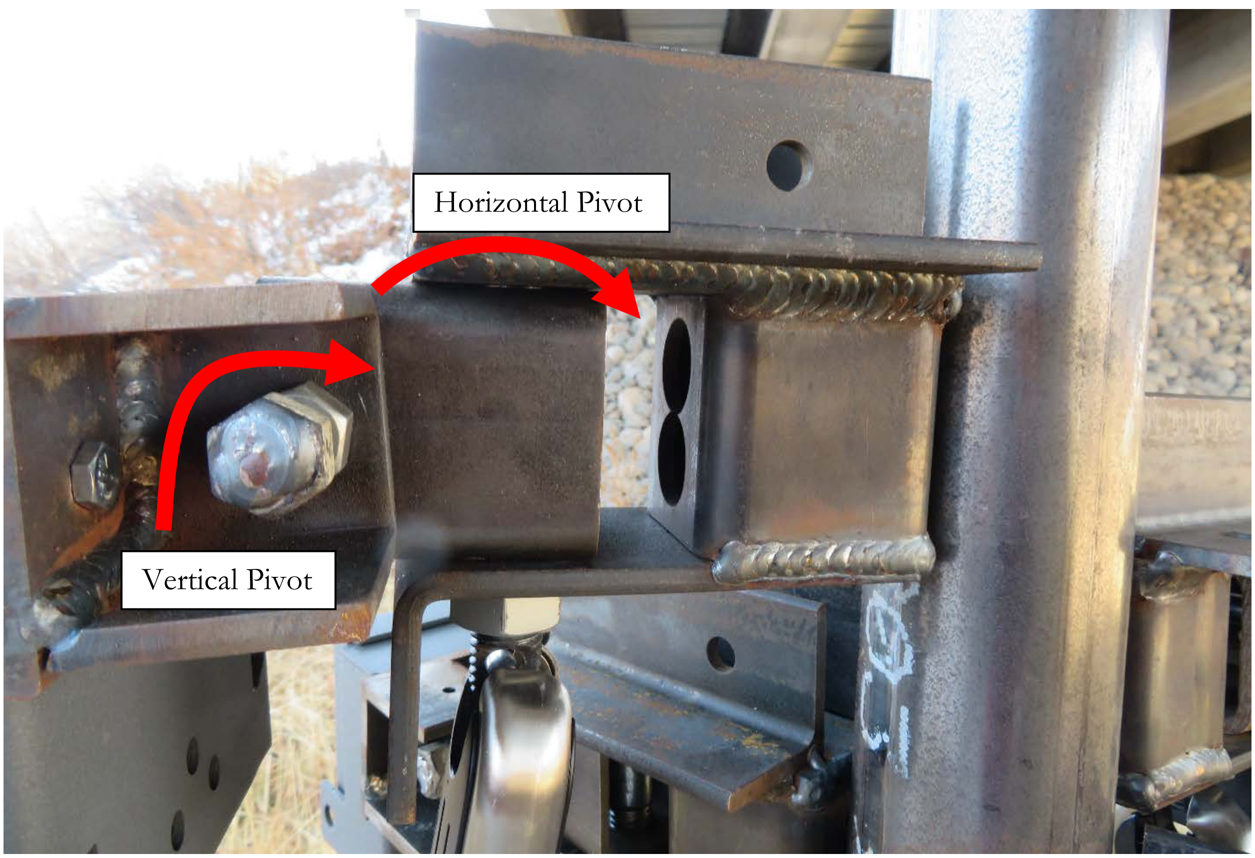

Figure 21. Mounts.

We used the latest version of Reconyx wildlife camera traps available at the time of purchase, the HP2X HyperFire 2 Professional Covert Infrared Camera (Figure 7). The cameras use motion-detection bands instead of a cone of detection and detect both movement and changes in temperature of bodies in the field of vision. Range is approximately 40 feet and the cameras are set to trigger when both motion and a difference in temperature are detected. Wildlife can be tracked at night with either a visible light or infrared flash. The cameras can record either pictures or videos and also record the temperature of the surrounding environment. Advertised operating temperature is -20 degrees to +120 degrees Fahrenheit (the lowest temperature we recorded in the field was -9 degrees Fahrenheit). Trigger speed is 0.2 seconds.

We set the flash to infrared and programmed the cameras to take 3 pictures per trigger. The camera is set to military time. We used twelve lithium AA batteries for longevity and 16GB SD cards. We preprogrammed the SD cards with our desired operating characteristics using software provided by Reconyx.

We installed the steel poles on October 12, 2019 and the cameras and mounts on November 13, 2019. We started data collection at approximately 5:00 PM on November 13, 2019 and completed data collection for this report at approximately 3:00 PM on June 17, 2020. Data will continue to be collected until at least November 13, 2020 for the implementation phase of this project. We checked on the cameras every 4-6 weeks throughout the study period. When checking the cameras, we uploaded existing images to a local memory source and examined the images to ensure the cameras were working properly (i.e., covering the study area, not being triggered by vegetation, etc.). We did not run into any issues with the cameras and there was no vandalism or theft.

We obtained motor vehicle collision data from NMDOT. The dataset includes all motor vehicle crashes that were reported to police and resulted in a human death, personal injury, or at least $500 in property damage. We reviewed all reported motor vehicle collisions from 2010-2018 and WVCs from 2002-2018. Crash data was provided in GIS point shapefile format. We were not able to obtain carcass counts because the Chama NMDOT patrol yard did not consistently tally them throughout the study period.

5. ANALYSIS AND FINDINGS

Although only seven months of data were collected at the time of this report (from mid-November 2019 until mid-June 2020), we provide a preliminary analysis of these observations. We will provide an entire 12-month analysis for the following Implementation Report.

Over the seven months for which we collected data, we recorded 96,256 pictures of wildlife. These pictures captured 1,438 individual animals. The cameras occasionally detected false positives, particularly when there was high temperature and/or wind. We deleted any false positives from the dataset and did not include them in our previous number or for the rest of the analysis. We also deleted pictures of humans and pets when they were accompanied by people. Such observations were limited, but we did occasionally detect people inspecting the bridges and fixing fences. Most animals entered the frame from the side or from a distance, as would be expected if the cameras were operating correctly. The animals also appeared across multiple cameras as would be expected. There were only a few instances of an animal appearing or disappearing from the middle of the frame, but we believe that the majority of animals were detected by the cameras.

54,762 pictures of wildlife that accounted for 506 animals were recorded at bridge #9387 and 41,494 pictures of wildlife that accounted for 932 animals were recorded at bridge #9415 (Table 2). Rates of pictures per animal were higher at bridge #9387 because many of the elk stopped to eat in front of the cameras at that crossing.

Table 2. Wildlife approach and passage counts and passage rates.

	#9387			**#9415**		
	Approach	Passage	Passage Rate	Approach	Passage	Passage Rate
Bobcat	5	3	60.0%	0	0	na
Cat	0	0	na	2	2	100.0%
Cow	22	9	40.9%	236	153	64.8%
Coyote	9	2	22.2%	40	24	60.0%
Deer	183	162	88.5%	76	64	84.2%
Dog	7	4	57.1%	12	12	100.0%
Elk	247	217	87.9%	563	487	86.5%
Fox	7	5	71.4%	1	0	0.0%
Great Blue Heron	1	0	0.0%	0	0	na
Horse	9	0	0.0%	0	0	na
Rabbit	0	0	na	1	1	100.0%
Raccoon	0	0	na	1	1	100.0%
Turkey	16	16	100.0%	0	0	na
Total	**506**	**418**	**82.6%**	**932**	**744**	**79.8%**

There were ten species of animal detected at bridge #9387 and nine species at bridge #9415 (Table 2). Both bridges had high numbers of elk and deer. Bridge #9415 also had particularly high numbers of cattle, along with higher numbers of elk and coyote. Bridge #9387 had higher number of deer, bobcat, fox, and turkey.

Of the 506 animals that were detected at bridge #9387, 418 (82.6%) animals passed under the bridge, 37 (7.3%) only approached the bridge, and 51 (10.1%) moved lateral along the bridge without passing under. Of the 932 animals that were detected at bridge #9415, 744 (79.8%) animals passed under the bridge, 42 (4.5%) only approached the bridge, and 146 (15.7%) moved lateral along the bridge without passing under. There were higher rates of lateral movement at bridge #9415 because a fence was installed for cattle and their lateral movements were detected. There were similarly low passage rates for horses because of fencing that prohibited their crossing. However, this fencing was not observed to prohibit the movement of wildlife. Passage rates were relatively low for coyotes because of high lateral movement and seemingly not because the crossing structures were inadequate for the species (we only observed one coyote that approached, turned around, and left in the same direction that it had approached). All other wildlife passage rates were relatively high. Similar passage rates between the bridges indicate that the smaller size of #9387 does not hinder wildlife movements.

Animals were primarily detected at night (Figure 22). Elk peaks were similar for both bridges with the most detections occurring approximately 22:00-02:00 and 06:00-08:00. Deer peaks were similar but a little earlier with peaks around 19:00-21:00 and 05:00-07:00. There were few detections 09:00-18:00. This was especially true for elk with only ten elk detected (out of the 810 total, or 1.2%) in the nine hours between 09:00-18:00.

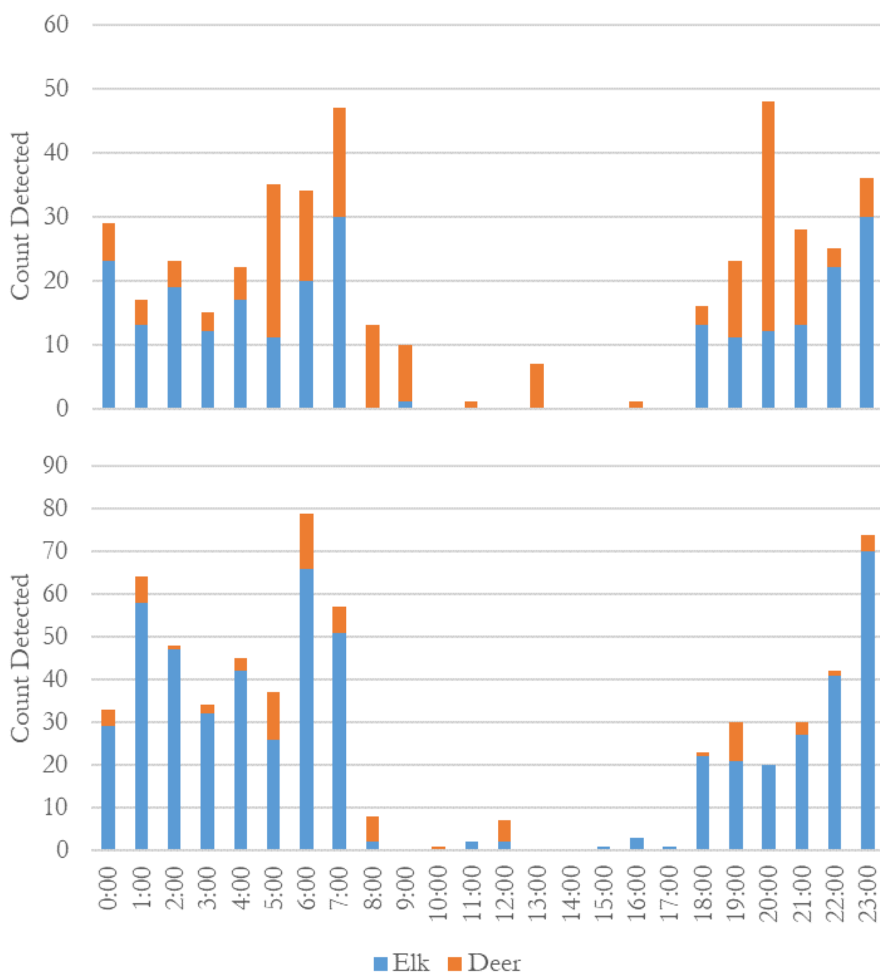

Figure 22. Time of day for elk and deer detections. Bridge #9387 top; bridge #9415 bottom.

Detection of species other than deer and elk were more evenly distributed throughout the day (Figure 23). The even distribution is especially evident at bridge #9387, which had 15 of 41 (36.6%) crossings other than deer and elk occur in daylight between 10:00-18:00. Most of these were bobcat, cattle, and coyotes. However, there were still peaks present in the evening and just before dawn at both crossing structures.

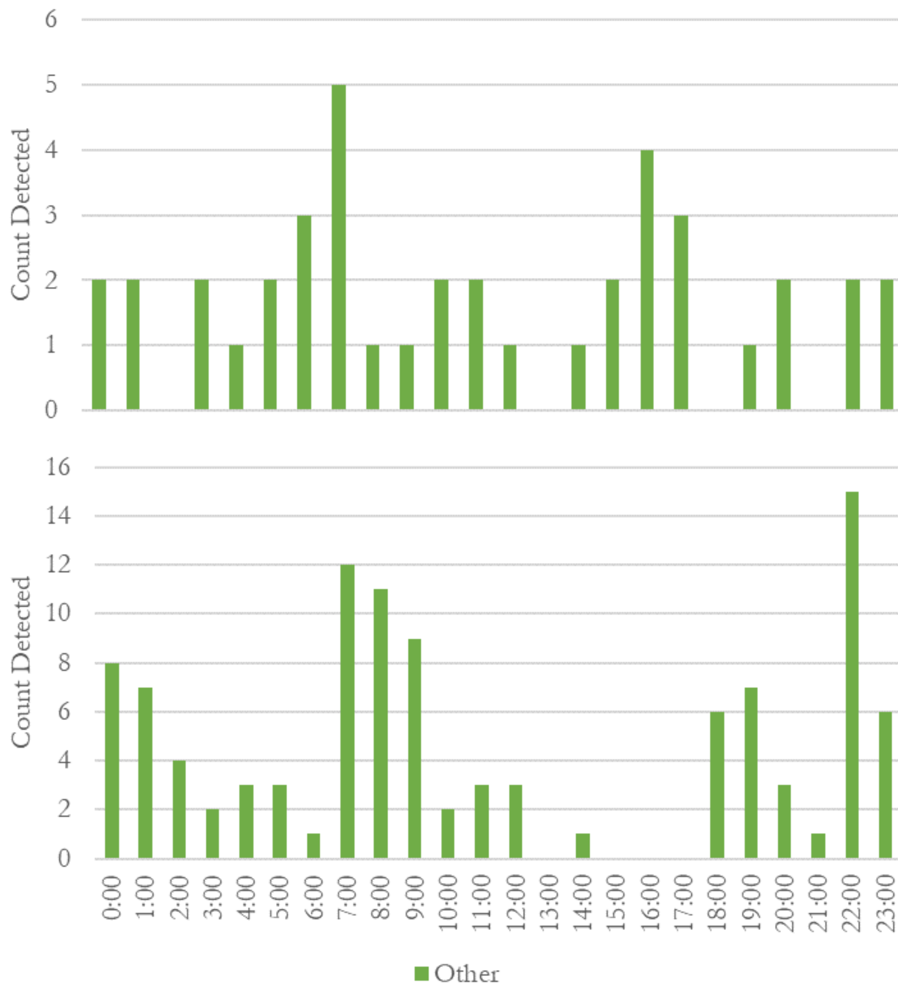

Figure 23. Time of day for detections other than deer or elk. Bridge #9387 top; bridge #9415 bottom.

In terms of seasons, there was little mixing between deer and elk (Figure 24). Other species were more evenly distributed throughout the year. Note that at the time of this report, data was only collected for the latter half of November and the earlier half of June and none of July-October. While deer were the most prevalent sighting in November for both crossing locations, the last deer detected in 2019 was on November 28 for #9415 and December 16 for #9387. There were no additional deer detected until April 14 for #9415 and May 9 for #9387. Once deer began appearing in the spring, their numbers increased rapidly.

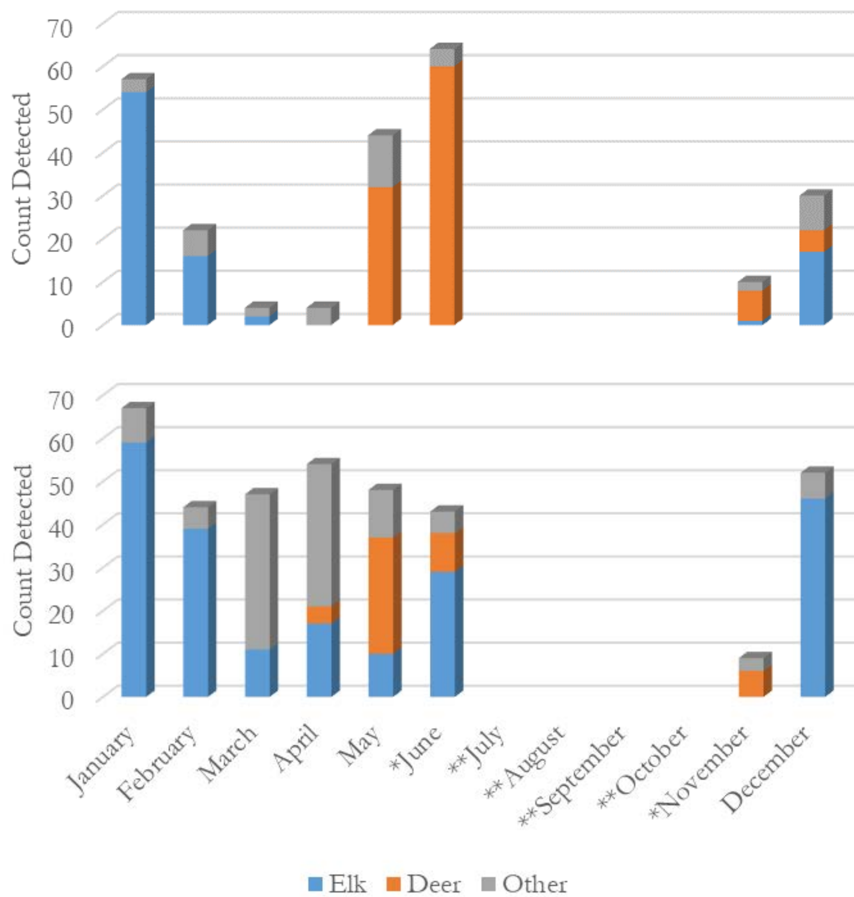

Figure 24. Month of detection for deer, elk, and other animals. Bridge #9387 top; bridge #9415 bottom. (*note: data was only collected for half of November and June and none of July-October*).

The first elk were detected on November 23 for #9387 and December 1 for #9415 (Figure 24). Elk were prevalent throughout December, January, and February. Elk sightings largely ceased at the end of February for #9387. However, elk continued to pass under bridge #9415. The continued passage of elk at #9415 was at least in part a result of mating as three juvenile elk began to be frequently detected with three adult female elk beginning on June 4 and continuing until the end of the data collection.

Detection of species other than deer and elk was again more evenly distributed (Figure 24). The high counts of species other than deer and elk in March and April for bridge #9415 were a result of increased cattle activity.

We were able to determine gender for deer and elk. More male elk were detected early in the season in December and January (Figure 25). More male deer were detected early in their season in June.

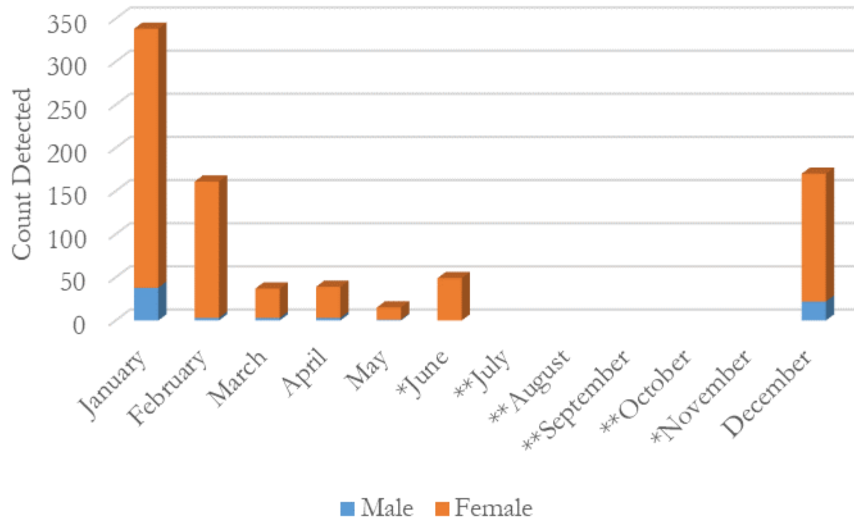

Figure 25. Elk by gender both bridges.

Detected wildlife were predominately moving south in November through February and predominately north in March through June (Figure 26). In terms of approaches (just approaches, without full passage), bridge #9387 experienced nine animals that approached northbound (and departed southbound) and eleven animals that approached southbound (and departed northbound). Bridge #9415 experienced ten animals that approached northbound (and departed southbound) and twelve animals that approached southbound (and departed northbound). These findings indicate that no one approach to the crossing structures is less likely to be used than any other.

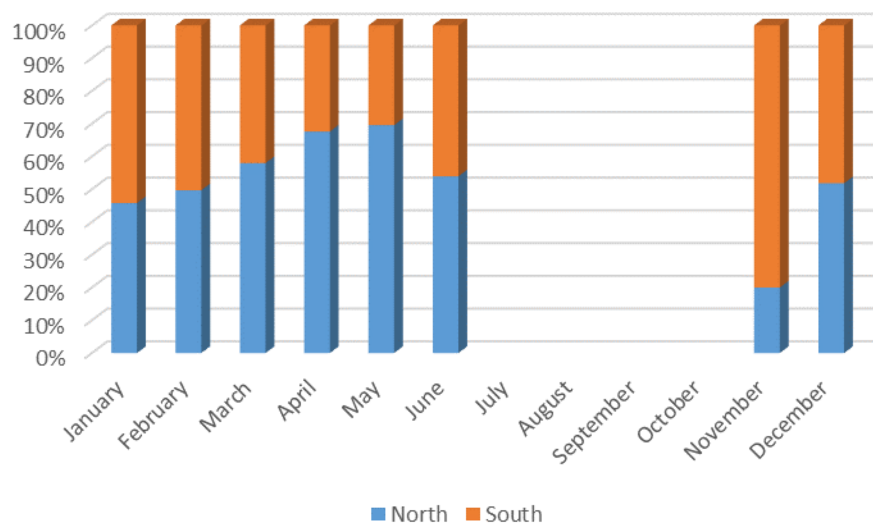

Figure 26. Crossing direction for all species by month.

This concludes the analysis of our wildlife observations from our monitoring equipment. Again, this is only informed by seven months of data analysis. We will complete a more comprehensive analysis for twelve months of observational data with our Implementation Report. We also analyzed the frequency of WVCs that were reported to police and were included in NMDOT motor vehicle collision data. Reported WVCs have been reduced by more than 85% since the 2012 installation of the wildlife fencing and crossing structures. Reported WVCs decreased from 1.4 WVCs per year for the eight years before installation to 0.2 WVCs per year for the six years after installation (Figure 27). All reported WVCs have involved deer or elk. Importantly, six of the eleven WVCs (54.5%) before installation involved elk while there has not been a reported elk collision in the last six years since 2012. Being the largest wildlife species present on the corridor, eliminating WVCs involving elk is especially important. Deer collisions have also decreased from five reported collisions in the eight preceding years to one collision in the six proceeding years.

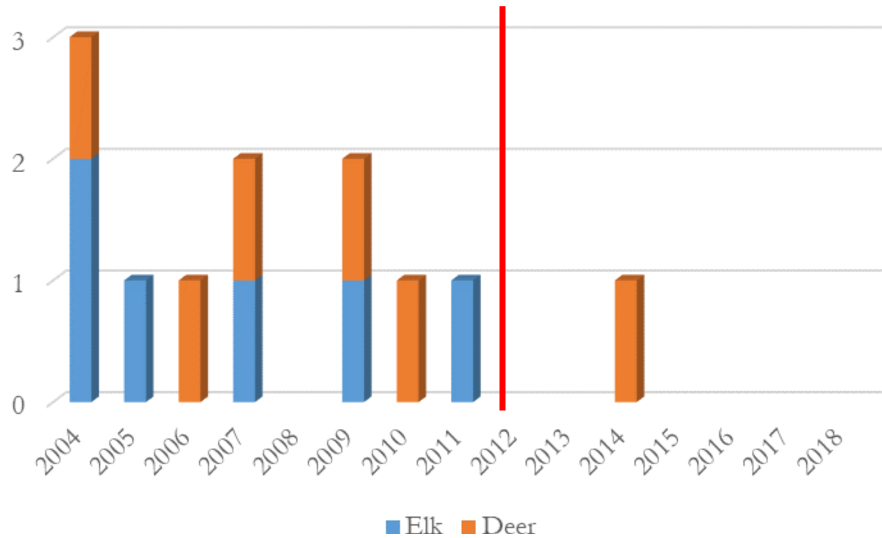

Figure 27. Motor vehicle crashes with installation in red.

All elk WVCs occurred in the early evening (Figure 28). This coincides fairly well with our observed peak of elk activity from 22:00-02:00, although we would expect WVCs to be more prevalent a bit earlier when there is more motorist activity. Interestingly, deer WVCs that occurred before installation happened primarily during daylight hours. After installation, the lone deer WVC occurred before sunrise.

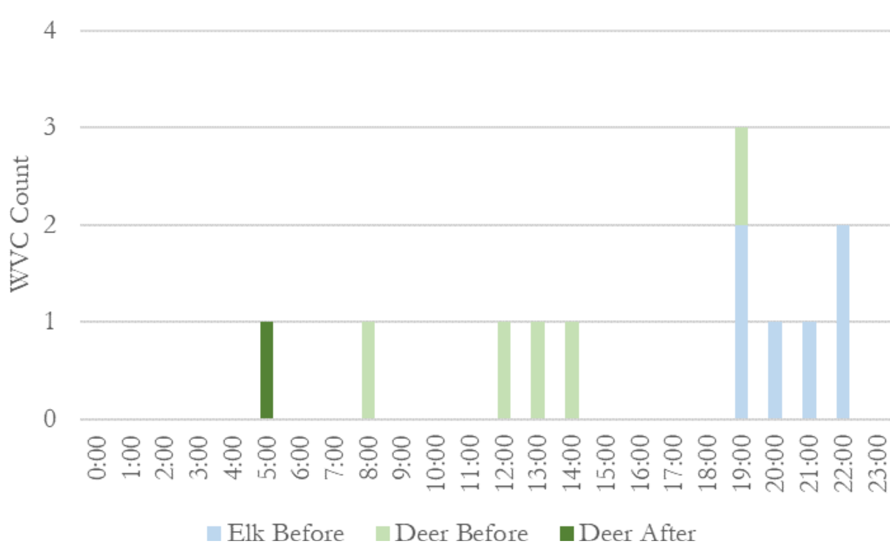

Figure 28. WVC by time of day.

While there was only one WVC post-installation on the fenced corridor itself, there were an additional three WVCs within close proximity of the fence ends after installation. These occurred in 2014, 2015, and 2018. There were no WVCs near the fence ends before installation. This suggests that further warnings or detection systems near the fence ends may lend themselves to a more complete WVC mitigation system. Further investigation into this possibility is warranted.

6. CONCLUSIONS

The most substantial contribution of this project was the methodology developed. Possibly more so than the data collected up to this point, the method of collection provides important and novel knowledge to the field of road ecology. The monitoring sites have been consistently collecting data for seven months with no vandalism or theft and minimal apparent missed captures. Based on methods developed by AZGFD, the monitoring bracket design – which allows for horizontal and vertical pivoting, securing of monitoring equipment, and theft and vandalism prevention – may be used by future researchers as they continue to innovate monitoring techniques and expand our understanding of road ecology.

While we have only collected data for seven months, the preliminary findings are promising and contribute to our knowledge of New Mexico highways. Deer and elk both appear to have no hesitations in using both the smaller and larger underpasses, with similarly high passage rates at both structures. This furthers our understanding of what types of structures large mammals – the most destructive species for WVCs – will utilize. Numerous other species have been found to use the crossings, bettering our overall understanding of the ecology of the region. Bobcats and foxes have been prevalent at bridge #9387 while coyotes have been prevalent at bridge #9415. An opportunity for future research has been identified through the fact that post-installation WVCs are present at the ends of the game fencing. While the project has been successful at decreasing WVCs, we might further explore how to effectively transition wildlife crossing projects with additional signage, either static or dynamic through wildlife detection.

Another contribution of this work is in terms of the wider WVC mitigation and wildlife conservation efforts underway. While we will not realize the impacts that this project has on the larger efforts until those projects have been further developed, this project will be an important piece in a larger puzzle being compiled across New Mexico and the entire region. This project plays an important role in three larger projects: 1) an on-going collaboration between NMDOT and AZGFD exploring WVC mitigation effectiveness, which is currently entering Phase 2; 2) a multi-state pooled fund study organized by several western states exploring WVC mitigation effectiveness; and 3) the New Mexico Wildlife Corridors Act, SB228, focused on WVC mitigation, which was recently passed through the New Mexico legislature.

While the current project has made important contributions, there have also been limitations. A primary limitation is that we are only monitoring two crossing structures. Even with the two sites that are relatively close geographically, we have observed variability in wildlife patterns. To get a complete understanding of wildlife habitats and migration patterns for all species, we will need to test many more sites. Furthermore, we only tested one type of crossing for the current project. While underpasses have been shown to be effective and economical per our literature review, it would be interesting to test other crossing structure types. Specifically, would passage rates for large mammals remain high for smaller structures? Would more expensive overpasses be worth the additional cost if passage rates were to increase or WVCs further decrease? Additionally, we have only collected seven months of data. To understand a full cycle of wildlife movements, we need a complete twelve months of data. To understand variability between migrations and to therefore appreciate how much confidence we may have in our data, we will need several years of data. A necessary limitation in this field of study and an opportunity for future research is the time scale at which wildlife movements take place.

Taking this project further, next steps will be to continue to collect data and perform analysis. However, before fully integrating into the highway system, we may also consider continuing to optimize the methodology. Installation of the steel pole, footer, and monitoring setup with camera, enclosure, and mounting bracket is a time- and labor-intensive process. Are there other materials that may allow for easier installation of a pole or alternative monitoring equipment that would allow us to install onto existing structures? Is it even possible to devise a method for mobile monitoring sites where one monitoring station may be moved to different sites along a corridor? The mounting bracket was effective, but we could probably simplify and optimize further. Finally, we might experiment with other cameras and monitoring equipment to understand which is most effective at capturing wildlife, especially smaller animals. While the existing methodology works and works well, there is room for further optimization before full implementation.

Several contributions have been realized through this project that will help advance ongoing WVC mitigation and wildlife conservation efforts, and several areas for future research have been identified. These findings will contribute to our goal of reducing costs, preserving our infrastructure, and saving lives for both humans and wildlife.

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